16 AUG 1939
RIAL
PARATE
E&A

Grasshoppers AND THEIR CONTROL

Farmers' Bulletin No. 1828

U.S. DEPARTMENT of AGRICULTURE

1939

GRASSHOPPERS in a single year have destroyed crops valued at over a hundred million dollars. The best way to prevent losses is the use of poisoned bait supplemented by tillage and seeding methods which restrict egg laying and imprison the young grasshoppers in the ground after they hatch.

Bait is most effective while grasshoppers are still on their hatching grounds or massed along field margins. It should be put out when grasshoppers are doing their first feeding of the day. This usually occurs between 6 and 10 a. m. at temperatures of 70° to 80° F. Bait should not be spread unless grasshoppers are actively feeding. In mixing and distributing the poisoned bait care should be taken to prevent injury to persons and farm animals.

Seeding grain only on plowed or summer-fallowed ground and plowing infested stubble before the eggs hatch greatly reduces the quantity of bait needed for control and decreases the liability of crop injury.

Cooperation in the use of control methods by all the farmers in a community is necessary for best results.

This bulletin supersedes Farmers' Bulletin 1691, How to Control Grasshoppers in Cereal and Forage Crops.

430
240
1732

Washington, D. C. Issued June 1939

Cat.

GRASSHOPPERS AND THEIR CONTROL

By J. R. PARKER, *senior entomologist, Division of Cereal and Forage Insect Investigations, Bureau of Entomology and Plant Quarantine* [1]

LL.

CONTENTS

	Page
Regions in which serious grasshopper damage occurs	2
Losses caused by grasshoppers	2
How grasshoppers injure crops	5
Principal kinds of injurious grasshoppers	6
Seasonal development and habits	10
How weather affects grasshoppers	13
Natural enemies	14
Artificial distribution of grasshopper diseases ineffective	15
How grasshopper outbreaks develop	17
How to control grasshoppers	18
Poisoned bait	18
Tillage and seeding methods	29
Additional suggestions for control	34
Organizing for grasshopper control	36

GRASSHOPPERS have always been among the chief insect enemies of agriculture in the United States. They are recorded as having injured crops in New England in 1797, and in 1818 vast hordes destroyed the crops of early settlers in the Red River Valley in Minnesota. During the period 1874 to 1877 the Rocky Mountain grasshopper, or locust, as it was then called, increased to such numbers that its depredations were considered a national calamity. Great swarms originating in the plains east of and adjacent to the Rocky Mountains in Montana, Wyoming, and Colorado migrated eastward to the Mississippi Valley and southward to Texas, devouring crops wherever they paused in their flights. Damage to crops amounted to $200,000,000. Congress recognized the seriousness of the outbreak and on March 3, 1877, created the United States Entomological Commission and authorized it to investigate the grasshopper problem. This organization, headed by C. V. Riley, developed into the Division of Entomology of the United States Department of Agriculture, which has now become the Bureau of Entomology and Plant Quarantine.

For some time it was believed that grasshoppers would become less abundant as the Western States became more thickly settled and more land was brought under cultivation. It now appears that the present large acreages of crops and idle land, added to the natural breeding grounds, offer grasshoppers a greater, more varied, and more succulent food supply than did the native grasses and that conditions are now more favorable for their development than before the land was disturbed by man. Grasshopper control must therefore be recognized as a permanent problem which should include not only the killing of grasshoppers after they become dangerous numerically, but also the adoption of such tillage and seeding methods and other farm practices as are known to check grasshopper increase.

[1] Acknowledgment is due R. L. Shotwell and W. R. Walton, of the Bureau of Entomology and Plant Quarantine, for inclusion of information previously published in Farmers' Bulletin 1691, How to Control Grasshoppers in Cereal and Forage Crops, of which they were joint authors, and members of the staff of the Bureau of Entomology and Plant Quarantine field laboratory at Bozeman, Mont., who took many of the photographs and performed much of the field work upon which recommendations and statements made in this bulletin are based.

REGIONS IN WHICH SERIOUS GRASSHOPPER DAMAGE OCCURS

Grasshopper outbreaks in the United States are largely confined to the following regions: Northern Great Plains, including eastern Montana, North Dakota, South Dakota, Nebraska, and Kansas; Rocky Mountain and Plateau States, including western Montana, Wyoming, Colorado, Idaho, and Utah; upper Mississippi Valley, including Minnesota, Iowa, Illinois, and Missouri; and the Great Lakes region, including Michigan and Wisconsin. Occasional outbreaks have occurred in California, Oregon, and Washington on the Pacific coast; in Arizona, Nevada, and New Mexico in the Southwest;

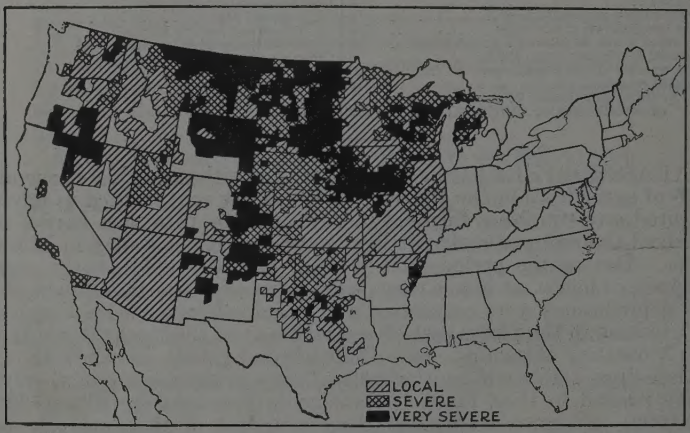

FIGURE 1.—Where grasshopper outbreaks occurred from 1931 to 1938.

in Arkansas, Oklahoma, and Texas in the South; and in the New England States. Some local damage is done each year by grasshoppers in other Eastern States, but, in general, severe, extensive outbreaks are confined to the western two-thirds of the United States.

The vast area subject to serious grasshopper injury can be visualized by looking at figure 1. It is based on surveys conducted since 1931 to determine where grasshoppers and their eggs were present in dangerous numbers and shows, by counties, where outbreaks have occurred during 1 or more of the years from 1932 to 1938.

LOSSES CAUSED BY GRASSHOPPERS

Reference has already been made to the destructiveness of grasshoppers during pioneer days, when no control measures were employed. Of more importance is the fact that enormous losses still occur because of the failure to make complete use of the effective control methods that have been developed by Federal and State entomologists since grasshopper investigations were inaugurated by Congress in 1877 (fig. 2).

FIGURE 2.—Grasshopper damage to corn. Frequently all the stalks in large fields are eaten to the ground.

FIGURE 3.—Grasshopper damage to wheat. Leaves are stripped and heads cut off.

In regions where conditions are favorable for their development, grasshoppers still remain the farmers' most dangerous insect enemy. Within the regions most subject to outbreaks are included the principal wheat-, barley-, and flax-producing areas of the United States. Included also are enormous acreages of alfalfa, corn, oats, and rye. All these crops are particularly susceptible to grasshopper attack, and there is never a year in which some damage is not done. This ranges from slight injury during years of ordinary abundance to total destruction of all crops over large areas when control measures are not employed during extensive outbreaks (fig. 3).

The monetary losses caused by grasshopper destruction of crops when viewed in the aggregate are staggering. For the 5-year period 1934–38, they amounted to approximately $315,753,000, and for the 10-year period 1929–38 the total was estimated to be $484,631,000. The distribution of losses by States from 1934 to 1938 are shown in table 1.

TABLE 1.—*Crop losses caused by grasshoppers during the period 1934–38* [1]

State	1934	1935	1936	1937	1938	Total
Arizona	$92,000	$92,000	$15,000	$16,000	$21,000	$236,000
Arkansas			275,000	318,000	215,000	808,000
California	1,500,000	450,000	443,000	179,000	70,000	2,642,000
Colorado	4,000,000	3,500,000	1,083,000	3,323,000	2,222,000	14,128,000
Idaho	230,000	15,000	25,000	150,000	300,000	720,000
Illinois	25,000	35,000	18,000,000	1,212,000	475,000	19,747,000
Iowa	1,000,000	625,000	25,000,000	7,238,000	1,101,000	34,964,000
Kansas	1,700,000	100,000	21,000,000	6,000,000	14,481,000	43,281,000
Michigan	500,000	219,000	43,000	354,000	432,000	1,548,000
Minnesota	500,000	750,000	800,000	1,002,000	1,261,000	4,313,000
Missouri	1,000,000	2,000,000	8,500,000	4,701,000	2,787,000	18,988,000
Montana	6,367,000	700,000	2,500,000	2,193,000	6,831,000	18,591,000
Nebraska	8,924,000	150,000	10,593,000	11,362,000	11,740,000	42,769,000
Nevada	72,000	32,000	14,000	7,000	114,000	239,000
New Mexico	800,000	500,000	250,000	229,000	42,000	1,821,000
North Dakota	361,000	100,000	100,000	7,695,000	24,556,000	32,812,000
Oklahoma	400,000	900,000	7,150,000	5,842,000	2,834,000	17,126,000
Oregon	400,000	100,000	100,000	200,000	34,000	834,000
South Dakota	4,000,000	2,500,000	3,000,000	4,999,000	13,674,000	28,173,000
Texas	1,000,000	1,000,000	1,000,000	3,332,000	1,767,000	8,099,000
Utah	200,000	435,000	1,529,000	3,463,000	651,000	6,278,000
Wisconsin	2,000,000	300,000	3,500,000	1,824,000	4,787,000	12,411,000
Wyoming	2,000,000	250,000	1,413,000	659,000	903,000	5,225,000
Total	37,071,000	14,753,000	106,333,000	66,298,000	91,298,000	315,753,000

[1] Acknowledgment is made to entomologists and county agricultural agents in the States listed for their assistance in making estimates of crop losses. In some instances previously published figures have been revised because of later and more complete county statistics, and in the cases in which detailed figures were supplied they have been rounded off to even thousands.

The total losses for each State for the 10-year period 1929–38 are shown in figure 4.

In addition to crop losses, extensive damage to range and pasture in some years amounts to millions of dollars in loss of feed and the forced sale of unfattened animals and breeding livestock.

Grasshopper damage to crops, pastures, and ranges has an important bearing on soil erosion. The almost-complete removal of the vegetative cover, which sometimes occurs during extremely severe outbreaks, leaves the soil highly susceptible to washing and blowing, which may keep it depleted for years (fig. 5).

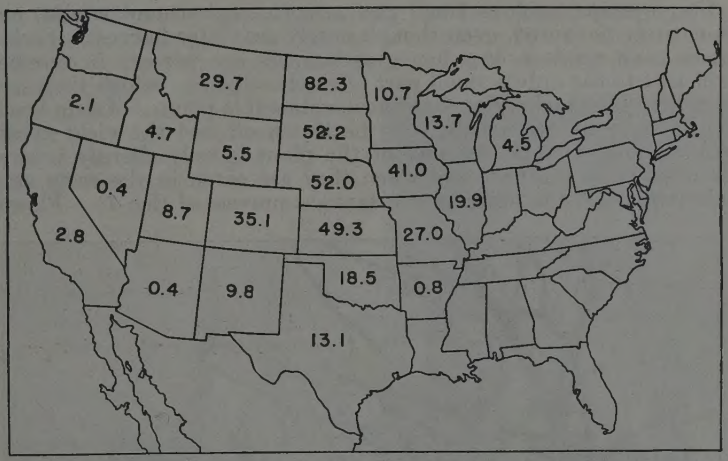

FIGURE 4.—Grasshopper damage in millions of dollars from 1929 to 1938.

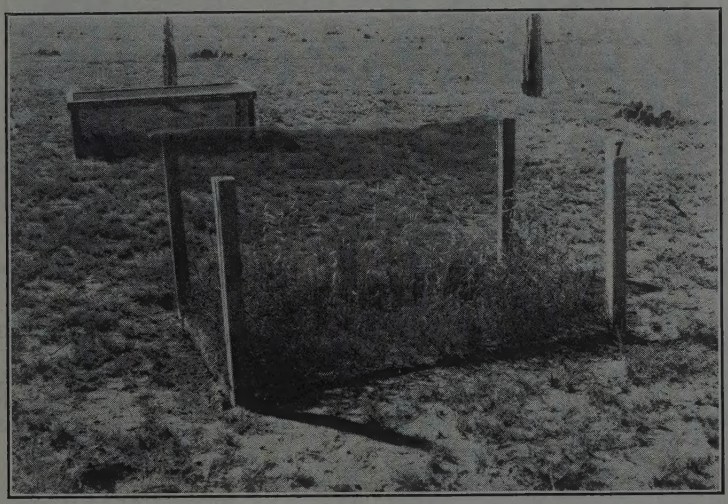

FIGURE 5.—Grasshopper damage to range grass. Note the shortness of the grass, the lack of seeding, and bare spots except where grama grass was protected by screening.

HOW GRASSHOPPERS INJURE CROPS

Some grasshoppers are limited to a single food plant, but the kinds that attack crops have more general food habits, and when food is scarce they will eat a wide variety of plants, shrubs, and trees. After crops and grasses have been destroyed they frequently eat the leaves and bark of deciduous trees (fig. 6) and occasionally feed on pines, firs, and spruces.

Staple crops, such as small grains, corn, cotton, and alfalfa, may be entirely devoured, even though nearly ready for harvest. Serious losses may result even when grasshoppers are present in numbers sufficient to eat only a small part of the host plants, which they seem to delight in attacking at their most vulnerable points. Grain heads, flax bolls, and cotton bolls may be bitten off and the yield greatly reduced even though the rest of the plant is only slightly injured. Corn silks are relished, and when they are eaten in the early stage pollination and the filling of the ears are prevented (fig. 7). Flowers

FIGURE 6.—Boxelder tree in midsummer after grasshopper attack. Note that even the bark has been eaten from some branches.

of alfalfa and sweetclover are preferred to the foliage, with resulting heavy losses to beekeepers and seed growers.

Young grasshoppers are as voracious for their size as are the adults; and since they hatch about the time spring crops are planted and the adults persist until fall, there is no part of the growing season when crops are immune to attack (fig. 8).

PRINCIPAL KINDS OF INJURIOUS GRASSHOPPERS

Every State within the regions subject to outbreaks contains at least a hundred different species of grasshoppers, some very rare, others fairly common, and a very few that occasionally become abundant enough to injure crops. At least 90 percent of all grasshopper damage to cultivated crops in the United States is caused by a small group of five species. These are the migratory grasshopper (*Melanoplus mexicanus* (Sauss.)), the differential grasshopper (*M. differentialis* (Thos.)), the two-striped grasshopper (*M. bivittatus* (Say)), the red-legged grasshopper (*M. femur-rubrum* (Deg.)), and the clear-winged grasshopper (*Camnula pellucida* (Scudd.)).

The migratory grasshopper (fig. 9) is reddish brown, with an irregular black patch on the neck or collar and is about 1 inch in length. Although comparatively small, it is a strong flier and sometimes gathers in great swarms which migrate long distances, injuring crops wherever they pause in their flight. It is found throughout the United States, but is most abundant in the northern Great Plains and the Rocky Mountain and Plateau States. It prefers well-drained, light soil and sparse vegetation for its breeding ground. The migratory grasshopper is similar in most respects to the Rocky Mountain locust, or grasshopper, which ravaged Western States years ago. The latter had longer wings and stronger powers of flight, characteristics which several species of grasshoppers are known to develop during periods of great abundance. The term "locust" was applied because of the similarity of the habits of the Rocky Mountain grasshopper to those of the locusts of the Old World. In most parts of the world the term "locust," or its equivalent, is used to designate grasshoppers that migrate in swarms. Thus the same species may be a grasshopper during its periods of small numbers and a locust when it is extremely abundant. In the United States everyone understands the term "grasshopper" as commonly used. It is less confusing to use the one term rather than to change to locust when grasshoppers fly in swarms. Another source of confusion is the fact that the 17-year cicada and its relatives, which are quite different insects, are popularly known as locusts.

The differential grasshopper (fig. 10) is yellow, with contrasting black markings and

FIGURE 7.—Ear of corn which did not fill because grasshoppers cut the silks before pollination was completed. Yields are often greatly reduced even though the leaves are only slightly damaged.

clear, glassy hind wings. The hind thighs bear distinctive black bars arranged like chevrons. It is a large grasshopper, nearly 1½ inches in length. Ordinarily it is a weak flier but, when extremely abundant, sometimes becomes migratory in habit and may fly long distances.

FIGURE 8.—Grasshopper damage to young wheat. Young grasshoppers invaded the field and ate the plants to the ground as they advanced. The farmer killed them with bait and saved the remainder of his crop. (Photograph by courtesy of J. A. Munro, North Dakota Agricultural Experiment Station).

It is seldom found farther north than the southern counties of North Dakota and Minnesota. It is found from the Atlantic to the Pacific coast but is most injurious in the Great Plains, upper Mississippi Valley, and Southern States. It prefers heavy soil for egg laying,

FIGURE 9.—The migratory grasshopper. Adult male. Twice natural size.

and rank-growing vegetation for food, being particularly fond of corn and soybeans.

The two-striped grasshopper (fig. 11) gets its name from the two conspicuous light-colored stripes which run the length of its back from the head to the wing tips. The general body color is greenish yellow,

with contrasting black or brown markings and colorless wings. It is slightly smaller than the differential grasshopper, but larger than the migratory grasshopper, measuring about 1¼ inches in length. It is found from southern Canada to Mexico, except in the South Atlantic States. It prefers heavy soils and succulent vegetation.

FIGURE 10.—Differential grasshopper. Adult male. Twice natural size.

The red-legged grasshopper (fig. 12) is reddish brown above and yellow beneath. Its hind legs are usually tinged with bright red, and its wings are colorless. It is smaller than the migratory grasshopper and about three-fourths of an inch long. It occurs throughout the United States. It prefers low, moist ground. Alfalfa is a favorite food plant.

The clear-winged grasshopper (fig. 13) is about the same size as the migratory grasshopper, measuring about 1 inch in length. Its

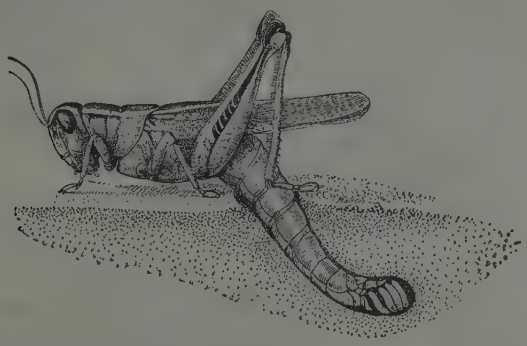

FIGURE 11.—Two-striped grasshopper: Female laying eggs. Slightly more than natural size.

color ranges from yellow to brown. The under wings are clear, but the front, or outer, wings are blotched with large brown spots. It occurs in all the Northern States that border Canada from the Atlantic to the Pacific, but is seldom found in more southern States. Its favorite habitats are mountain meadows, land from which timber has been removed, hay meadows, pastures, and roadsides. It is primarily

a grass feeder, but when present in outbreak numbers is very destructive to small grains. It is migratory in habit, both in the immature and adult stages. In some States it is called the warrior grasshopper, because the young grasshoppers frequently march in bands from one field to another.

In addition to the species of grasshoppers that commonly attack crops, there are numerous species that ordinarily feed on range and pasture vegetation and which, in times of food scarcity, occasionally attack crops. Fortunately most of the grass-feeding species are closely restricted in their feeding habits and only rarely attack crops.

FIGURE 12.—Red-legged grasshopper. Adult male. Three times natural size.

Among the most important range grasshoppers are the migratory range grasshopper of the Plains (*Dissosteira longipennis* (Thos.)), the big-headed grasshopper (*Aulocara elliotti* (Thos.)), *Ageneotettix deorum* (Scudd.) (no common name), the lubber grasshopper (*Brachystola magna* (Gir.)), and Packard's grasshopper (*Melanoplus packardii* (Scudd.)). The last is a border-line species that eats crops, as well as grasses. The migratory range grasshopper is the most spectacular and, during its rather infrequent outbreak periods, the most destructive of the range species. The young march in dense bands, sometimes several miles long and several hundred yards in width (fig. 14).

FIGURE 13.—Clear-winged grasshopper. Adult male. Twice natural size.

The adults gather in swarms and frequently fly long distances. This species is most abundant in Colorado, New Mexico, Oklahoma, Texas, and western Kansas.

SEASONAL DEVELOPMENT AND HABITS

The grasshoppers that attack crops have similar habits and develop in much the same way. The eggs are laid late in the summer and fall, remain in the ground during the winter, and hatch during April,

May, and June. There is generally only one generation a year, but in more southern States and sometimes during unusually hot summers in the North early-laid eggs may hatch the same year they are laid. None of the species that attack crops are able to survive the winter in the Great Plains except in the egg stage. However, there are several species of noneconomic grasshoppers that hatch in the fall and pass the winter in the half-grown stage. These often move about during warm spells in winter and become active very early in the spring, and are the cause of many misleading reports that grasshoppers are hatching.

The egg-laying habits of grasshoppers differ and are important from the standpoint of control. The migratory grasshopper lays its eggs throughout grain and other crops and in idle land that has grown up to weeds. The differential and two-striped grasshoppers lay very few eggs within fields bearing crops, but instead prefer sod and weedy ground bordering the crop upon which they are feeding. The clear-winged grasshopper lays its eggs almost entirely in sod, and frequently selects for oviposition small areas, in which the eggs are densely packed, females coming long distances to lay eggs in these areas and then leaving to feed again.

The eggs of grasshoppers are enclosed in sacs, or "pods," formed of a glutinous substance excreted by the female as the eggs are laid. The female thrusts her abdomen, which is capable of considerable extension, into the soil to a depth of an inch or two and starts laying her eggs at the bottom of the tunnel thus formed, which is then filled with eggs and sealed (fig. 15). The number of eggs in each pod varies with the species. The egg pods of the clear-winged and migratory grasshoppers usually contain from 15 to 20 eggs, while those of the differential and two-striped grasshoppers have from 50 to 75. The number of pods laid by each female varies according to the species, the food supply, and weather conditions. A female migratory grasshopper held in a cage laid 21 pods. The two-striped grasshopper has been known to lay 12 pods, and the differential grasshopper 8.

The egg pods are very resistant to moisture and cold, and are affected but little by winter conditions if the ground is not disturbed. Hatching takes place in the spring, when air temperatures range from 75° to 80° F. for several days in succession. Eggs of migratory and two-striped grasshoppers have a more rapid rate of development and hatch from 2 to 3 weeks earlier than those of differential and red-legged grasshoppers in the same locality.

In contrast to many other injurious insects, grasshoppers, when newly hatched, closely resemble their parents, except for size and lack of wings. There is no grublike larval stage, nor is there any resting or true pupal stage, such as that of butterflies and moths. The young grasshoppers are active and able to hop almost immediately upon emergence from the egg. They require from 40 to 60 days, depending on weather conditions, to mature and acquire wings. During this time they shed their skins five or six times. The cast-off skins are often mistaken for dead grasshoppers and frequently are the basis of mistaken reports that grasshoppers are "dying by the millions." The appearance of fully developed wings, except in wingless species, marks the final stage of growth, and the grasshopper is then ready to mate and reproduce.

FIGURE 14.—Migratory range grasshoppers on the march. Bands are often several miles long and an eighth of a mile wide. (Photograph by Soil Conservation Service, U. S. Department of Agriculture.)

HOW WEATHER AFFECTS GRASSHOPPERS

Fairly dry, warm weather is favorable for grasshoppers; cool, wet weather, with long periods of high humidity, is unfavorable. Newly hatched grasshoppers, like most young animals, are delicate creatures and are difficult to raise, even in the laboratory when the most favorable conditions known are provided. Unless they feed and their digestive systems start functioning normally soon after hatching, a high percentage of them die within a few days. Weather conditions immediately after the hatching determine to a great extent the numbers that survive. If hatching is brought about prematurely by abnormally high temperatures early in the spring and this is followed by weather that is too cold for general feeding, which begins at 70° F.,

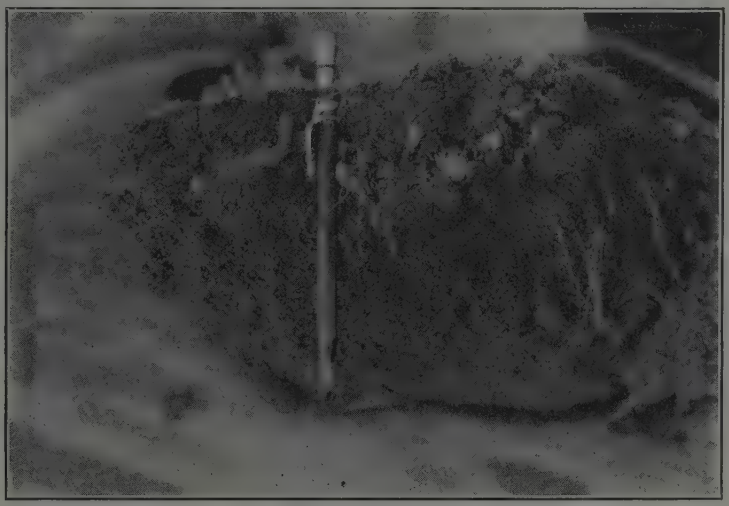

FIGURE 15.—Grasshopper eggs in soil. Their size can be judged by comparing them with the 5-inch pencil.

great numbers of them die. Unseasonably cool weather late in the spring after the normal hatch has taken place may have a similar effect in reducing numbers. On the other hand, if the hatching of the eggs is followed by several weeks of continuously warm, dry weather, the young hoppers get off to a vigorous and healthy start, and nearly all those that have hatched survive the critical early stages.

Rainfall affects grasshoppers in a number of ways. Heavy rains during or immediately following the hatching period may kill the young grasshoppers by washing them into streams or embedding them in wet soil. Periods of a week or more of continuously cloudy, wet weather, with the relative humidity close to the saturation point, are favorable for the development of bacterial and fungus diseases, which sometimes kill grasshoppers in large numbers. Total precipitation is less important in starting grasshopper diseases than continued cloudiness and high humidity. A fall of several inches of rain in a day or

two, followed by bright sunshine, has little effect, while the same amount, or even less, scattered through a week of continuously cloudy weather may start an epidemic of disease. While rainfall is generally detrimental to grasshoppers, the most extreme drought conditions are also unfavorable. Grasshopper eggs in some types of soil cannot hatch while it is extremely dry and may become so shrivelled that they fail to hatch when the soil is moistened. Drought conditions may also reduce plant growth to such an extent that grasshoppers may starve. Even if they survive a period of starvation, their egg production may be greatly reduced by insufficient food.

Temperature is important in determining the number of eggs laid. High temperatures during the summer and fall bring early maturity and provide a long period for egg laying. Low temperatures have the opposite effect.

An ideal season for the maximum increase in grasshopper numbers would be as follows: Cool, wet weather during the early part of the spring to prevent premature hatching and to insure an adequate food supply after hatching takes place; several weeks of continuously warm, dry weather late in the spring to facilitate a complete hatch and optimum feeding conditions; a hot summer with sufficient rainfall to maintain an ample food supply, but with no wet periods long enough to stimulate grasshopper diseases, and a late fall to insure early maturity and maximum time for egg laying.

A season favorable for heavy mortality of grasshoppers would have the following characteristics: Weather warm enough early in the spring to cause considerable premature hatching, followed by temperatures low enough to prevent normal development; a short period of hot weather late in the spring to insure complete hatching of the remaining eggs, followed by long periods of cloudy, wet weather favorable for grasshopper diseases; a cool summer and early fall to delay maturity and shorten the time for egg laying.

Winter weather has little effect upon grasshopper abundance. Sound eggs located in the ground at the beginning of the winter will nearly all hatch the following spring.

NATURAL ENEMIES

Grasshoppers have many natural enemies. Some of these attack the immature and adult stages, while others prey upon the eggs. Some of them attack at one season, some at another, but there is no period of the entire year when the grasshoppers or their eggs are entirely safe from their numerous enemies. Without the combined destructive action of their natural enemies, the artificial control of grasshoppers by man would be much more difficult and probably impossible.

Some of their more important enemies are flesh flies, bee flies, blister beetles, ground beetles, spiders, hairworms, rodents, birds, and diseases.

Flesh flies deposit active maggots upon grasshoppers, even while the latter are in flight. The tiny maggots work their way into the body and feed upon its contents, leaving the more vital organs for final feeding. There are several generations of flesh flies in a single season, and this allows them to increase manyfold in one summer. When flesh flies are abundant they frequently kill large numbers of

grasshoppers by midsummer and infest so many of those remaining alive that egg laying is greatly reduced.

Bee flies, blister beetles, and carabid beetles lay their eggs in the soil close to grasshopper egg pods, or even in them. The larvae, or maggots, work their way into the egg pods and usually consume them entirely. These predators have been known to destroy from 40 to 60 percent of all the grasshopper eggs laid over large areas.

Spider webs trap surprisingly large numbers of immature and adult grasshoppers. Even the largest grasshopper is securely bound with silken strands within a few seconds after it becomes entangled in a web.

In some States hairworms are common parasites of grasshoppers. Hairworms are long, whitish, extremely slender worms, frequently found coiled within the body cavity of living grasshoppers. Grasshoppers thus infested may live from 1 to 3 months but are retarded in their development, and the females are rendered sterile. When the worms complete their growth in the grasshopper, they kill it by forcing their way through the body wall. They then enter the ground.

Ground squirrels, field mice, and other rodents eat grasshoppers and dig in the ground for their eggs. No figures are available on the percentage of eggs destroyed by rodents, but it must be high, as evidence of their digging can be seen wherever grasshopper eggs are abundant.

The Bureau of Biological Survey has found that birds play an important part in the natural control of grasshoppers. All birds, except the strictly vegetarian doves and pigeons feed on grasshoppers, and some eat the eggs after scratching them from the ground. Birds are of great value in holding grasshoppers in check when the latter occur in moderate numbers but cannot be expected to prevent outbreaks entirely. It is often asserted by sincere nature lovers that recent grasshopper outbreaks are due to decreased numbers of game birds and songbirds. If their reasoning is correct, it becomes difficult to explain the severe grasshopper outbreaks which were common on the Great Plains 50 to 60 years ago when game birds were far more plentiful than now and before the natural distribution of songbirds had been disturbed by agriculture.

ARTIFICIAL DISTRIBUTION OF GRASSHOPPER DISEASES INEFFECTIVE

Fungous and bacterial diseases at times destroy great numbers of grasshoppers (fig. 16) and have been known to terminate outbreaks. It has already been pointed out that fairly long periods of wet, cloudy weather, with the relative humidity close to the saturation point, are favorable for their development. Unfortunately, these diseases do not flourish under the dry conditions which usually prevail during grasshopper outbreaks. The idea of controlling grasshoppers by artificially culturing and distributing grasshopper disease organisms has a strong appeal to the public, and some of its advocates become almost fanatical in their zeal for this method of control. Federal and State workers, during the period from 1895 to 1905, made many attempts to spread grasshopper disease by artificial cultures. They finally concluded

144619°—39——3

that the diseases become active of their own accord when weather conditions are favorable and that they cannot be started, even by by artificial cultures, when weather conditions are unfavorable.

FIGURE 16.—Grasshoppers killed by fungus. Note the characteristic way in which the dead bodies cling to vegetation. (Photograph by courtesy of G. A. Bieberdorf and C. F. Stiles, Oklahoma Agricultural and Mechanical College).

Similar experiments conducted during the same period in foreign countries gave similar results. More recently a thorough investigation by modern scientific methods was conducted in South Africa

to determine the possibility of controlling locusts by distributing artificial cultures of a fungous disease very similar to one that attacks grasshoppers in the United States. After 2 years of study the investigator concluded that the chances of controlling locusts by this method were exceedingly remote.

HOW GRASSHOPPER OUTBREAKS DEVELOP

During grasshopper outbreaks a frequent and natural question is: Where did they all come from? It is difficult for the average person to comprehend the wide fluctuations in numbers that occur unless he is aware of the potential reproductive capacity of grasshoppers and the many factors that check it during average years.

The female of the common migratory grasshopper (*Melanoplus mexicanus*) has been known to lay 400 eggs during a single season. The more usual number, during an average summer, is about 200, and perhaps only 40 eggs may be laid during an unusually cool year. It will thus be seen that 10 times as many eggs may be laid during an extremely favorable year as in an extremely unfavorable season by the same number of grasshoppers.

It should also be pointed out that if the female of a pair of grasshoppers lays 200 eggs in one season, 198 eggs or young grasshoppers must die before maturity if the adult population is to remain the same the following year. If, instead of only 2 adults surviving, there are 4, 6, 8, 10, or perhaps 50, then the adult population the following year will be increased 2, 3, 4, 5, or 25 times, respectively. The major natural factors that keep grasshoppers from increasing at the enormous rate of which they are potentially capable are unfavorable weather conditions, lack of food, and natural enemies, including disease. Assuming that half the eggs were destroyed by predators, that half of the young grasshoppers from the remaining eggs died shortly after hatching because of unfavorable weather, and that half of these survivors starved to death, there would still be 25 adults instead of the single pair that produced the 200 eggs the previous year. It can thus be easily seen that if natural enemies fail to destroy their usual quota, if weather is favorable and food ample, enormous increases in grasshopper numbers are possible in a single year.

Outbreaks are ordinarily preceded by several years of gradual increase in grasshopper numbers followed by a year that is unusually favorable. This results in a pyramiding effect, which produces astonishing numbers during the first year of the outbreak. At the low point between outbreaks less than 1 grasshopper per square yard is generally present in crops and other favorable habitats. When conditions become slightly more favorable there may be 2 per square yard. Then may come a year when numbers are doubled and there will be 4 per square yard, which is not enough to injure crops or attract attention. The following year may again result in twice the population of the previous year and still there would be only 8 per square yard, which is enough to cause slight injury to crops, but not enough to cause much comment. If the next year conditions are more favorable than in previous years, and numbers instead of being doubled are tripled or quadrupled, there will be 24 or 32 grasshoppers per square yard, which is enough to injure crops severely and to be considered an outbreak. The intensity of the outbreak depends

largely on the rate of increase during the final year. It has been shown that increases of considerably more than 4 times the number of the previous year are possible. An increase of 10 times in the illustration just used would result in 80 grasshoppers per square yard, and this is not unusual during the most severe outbreaks. With such numbers present, crops and native vegetation may be entirely devoured if man-devised control methods are not employed.

When an outbreak subsides there is generally a sudden drop to nearly normal numbers. This usually occurs following a year when weather conditions were highly unfavorable for the survival of young grasshoppers and for egg laying by adults and at a time when parasites and predators have reached maximum abundance.

HOW TO CONTROL GRASSHOPPERS

When grasshoppers become noticeably more than normally abundant, immediate action should be taken to control them, even though they are doing only slight damage to crops. Prompt use of control measures at this stage by all farmers within a community or county offsets the natural factors that are permitting the increase and may prevent the grasshoppers from reaching the serious outbreak stage. Unfortunately it is extremely difficult to persuade farmers to fight grasshoppers until their crops are seriously threatened. Their inclination is to wait and see what happens, meanwhile hoping that nature will come to their rescue, as it sometimes has in the past. More frequently the grasshopper population increases manyfold the following year and requires a much greater expenditure of labor and money for control than would have been necessary if action had been taken the previous year. If the wait-and-see attitude of the farmer could be overcome, it would eliminate one of the greatest difficulties in grasshopper control.

Whenever grasshoppers increase to such numbers that control is necessary, main dependence should be placed on destroying the young and adults with poisoned bait and the use of tillage and seeding methods that either destroy the eggs or prevent the emergence of newly hatched grasshoppers from the ground. One method supplements the other, and both must be used if successful and economical control is to be attained.

POISONED BAIT

The use of poisoned bait has proved to be a simple, reliable, and cheap way of killing grasshoppers. In the United States, Canada, and many other countries it is recognized by entomologists as the standard method of control and has replaced less effective methods. It has been used successfully by farmers in the United States for many years. During three of the larger control campaigns a million farmers spread a quarter of a million tons of bait on 65 million acres and saved crops valued at $328,000,000.

MATERIALS RECOMMENDED

Many materials have been used more or less successfully in making poisoned bait for grasshoppers. Availability, cost, and relative efficiency should be considered in making a selection. Experience

gained from the extensive farm use of grasshopper bait in recent outbreaks and from experimental tests indicates that sawdust can be substituted for much of the bran previously recommended and that grasshoppers in most cases are attracted to the bait without the addition of molasses, amyl acetate (banana oil), citrous fruits, or other strong-smelling substances.

The following bait formulas are recommended, in the order listed:

MILL-RUN BRAN AND SAWDUST

Mill-run bran, mixed feed, or shorts	pounds	25
Sawdust (3 times bulk of mill-run bran)	bushels	3½
Liquid sodium arsenite (32-percent arsenious oxide)	gallon	½
Water	gallons	10–12

The millfeeds recommended in this formula contain considerable quantities of flourlike material mixed with flakes of wheat bran. When moistened by the solution of water and sodium arsenite, the finer material forms a poisoned paste which coats the sawdust particles. Grasshoppers relish the flour paste, both for its food value and for its moisture content. They gnaw and chew the sawdust to obtain the paste and are killed by the poison it contains. The sawdust is not eaten after the flour coating and moisture have been completely removed. The flakes of poisoned bran usually are entirely consumed by feeding grasshoppers.

This mixture has been used in the extensive grasshopper campaigns of recent years and has given excellent control at low cost under varied conditions in the western half of the United States. Its large content of sawdust greatly improves the spreading qualities of the bait, and, in combination with millfeeds other than pure bran, greatly reduces the consumption of feed materials in baits. As a result, there is less disturbance of the millfeed market during seasons when large quantities of bait materials are being purchased.

STANDARD BRAN AND SAWDUST

Standard wheat bran	pounds	50
Sawdust (equal to bran in bulk)	bushels	2¼
Liquid sodium arsenite	gallon	½
Water	gallons	10–12

Standard bran does not contain as much flourlike material as mill-run bran and other more finely ground millfeeds. It does not coat the sawdust particles so thoroughly, and the killing action is obtained largely through the consumption of poisoned bran flakes. The sawdust acts mainly as a diluent and prevents lumping. This mixture has been widely used with good success and is recommended where other millfeeds are difficult to obtain.

Where sawdust is not available, an additional 50 pounds of wheat bran may be substituted for it in the above formula, but at an increase in cost.

LOW-GRADE FLOUR AND SAWDUST

Low-grade flour	pounds	10
Sawdust (equal in bulk to 100 pounds of bran)	bushels	4½
Liquid sodium arsenite	gallon	½
Water	gallons	10–12

The killing of the grasshoppers when this bait is used is due entirely to their feeding on the paste-covered sawdust particles. This bait

has given good results in experimetal tests conducted over a period of several years and has been used in several county-wide grasshopper-control campaigns. It is recommended where coarser millfeeds are not available or are unusually high in price.

MOLASSES AND SAWDUST

Sawdust (equal in bulk to 100 pounds of bran)	bushels	4½
Molasses (low-grade cane or blackstrap)	gallons	1½
Liquid sodium arsenite	gallon	½
Water	gallons	10–12

The killing action of this mixture on grasshoppers results from their eating the sticky coating of poisoned molasses adhering to the sawdust particles. This bait frequently has given as good kills in experimental work as the millfeed baits, but generally was slightly below them in killing power. It is recommended only when other materials are not available.

POISONS

Liquid sodium arsenite is the cheapest and most satisfactory poison. The so-called 4-pound material containing 4 pounds of arsenious oxide (32 percent) to the gallon is usually available commercially. One-half gallon is used for each 100 pounds of bran or equal bulk of sawdust. This quantity is considerably in excess of the actual requirements for killing, as good kills have been obtained with half this dose, but the grasshoppers die more slowly, and great care must be taken to distribute the smaller dose evenly throughout the bait. The greater quantity recommended gives maximum killing action and provides a margin of safety in mixing. The use of doses larger than those recommended does not further speed up killing action or increase the total kill.

Finely divided crude arsenic, obtained from copper smelters, can be substituted for liquid sodium arsenite. Five pounds should be used for each 100 pounds of bran or equal bulk of sawdust. Crude arsenic kills more slowly than sodium arsenite; it does not dissolve in water, and more labor and care are required in mixing it to obtain a uniform distribution of poison throughout the bait.

Paris green used at the same rate as crude arsenic gives equally good results but is more expensive.

Sodium fluosilicate, at the rate of 4 pounds to 100 pounds of bran or equal bulk of sawdust, has given excellent kills in experimental work. It is less toxic to animals than arsenic, and its use would lower the hazard of accidental livestock poisoning. It costs more than either liquid sodium arsenite or crude arsenic.

SAWDUST

Either hardwood or softwood sawdust may be used. Coarse-sawn dust is not so effective as the finer dust. Coarse material can be greatly improved by running it through a hammer mill. Sawdust that has remained in the pile for several years has softer fiber, is more absorbent, and makes a better bait carrier than the firmer particles of new sawdust. Fresh sawdust from extremely soft woods, such as poplar, may be used without ageing. Any bark, sticks, large chips, or other useless material should be removed by screening.

SAWDUST SUBSTITUTES

In localities where sawdust is scarce and the cost of shipping is prohibitive, an equal bulk of some other diluent may be substituted for the quantity of sawdust recommended in the various formulas. Corncobs ground to the consistency of coarse bran have been used extensively in Illinois, and in the Southern States ground cottonseed hulls have given excellent results. In experimental work conducted by the Nebraska Agricultural Experiment Station, cornstalks ground

FIGURE 17. Mixing poisoned bait by hand in a mixing box. (Photograph by Soil Conservation Service, U. S. Department of Agriculture.

in a hammer mill were substituted for sawdust without reducing the effectiveness of the bait.

MIXING THE BAIT

The bait can be mixed by hand on a tight floor or in a wagon box or similar container (fig. 17). In mixing sawdust and millfeed baits, the required quantity of sawdust should be spread out evenly over the floor to a depth of 6 or 8 inches. The millfeed should then be scattered uniformly over the sawdust and the two ingredients thoroughly mixed by turning with shovels. If one of the arsenic preparations or paris green is used, the required quantities of water and poison are mixed thoroughly in a large can or barrel. This mixture is then splashed

over the dry ingredients in three applications and the mixture turned with shovels after each wetting. When either crude arsenic or paris green is used the liquid must be vigorously agitated just before each portion is removed from the container, as otherwise the heavy insoluble poison settles to the bottom and an uneven mixture may result.

Sodium fluosilicate gives best results when it is thoroughly mixed with the dry ingredients before water is added.

Twice the quantity of materials listed in each formula is about all that can be mixed in a wagon box at one time, but on a floor where there is plenty of room the quantity can be doubled again. Good results depend on mixing the mash thoroughly until it contains no lumps, and is uniformly moist throughout. The quantity of water needed will vary somewhat according to the condition of the sawdust used. It is desirable to add as much water as the bait will absorb and still fall in individual flakes when scattered by hand. A good test for correct moisture content is to squeeze a handful of bait. If it drips moisture freely when lightly gripped, it is too wet. Properly moistened bait will drip only slightly when pressed firmly in the hand.

In county-wide campaigns where many tons of bait must be mixed, the best results can be obtained by establishing a central mixing station. A small crew properly supervised and using mechanical bait-mixing machines can prepare a more uniform bait at less cost than it can be mixed by hand on individual farms.

Many kinds of power mixers have been used. Some of the more common types are revolving boxes and churns, concrete mixers, and stock feed mixing equipment. The particular type to be selected in any community depends on available funds, equipment on hand, and the volume of bait to be mixed. Churns of the revolving-drum type and small concrete mixers are satisfactory when the quantity of bait needed does not exceed approximately 25 tons per day. Large concrete mixers of the batch type (fig. 18) or specially constructed large mixers which can be kept in continuous operation are desirable if a daily capacity of more than 25 tons is needed.

The selection, construction, and power requirements of large bait-mixing outfits and the arrangement of the mixing stations are problems that usually can be solved most successfully by the best mechanic in the community, working in close cooperation with the county agricultural agent. The following basic requirements should be kept in mind:

(1) **Facilities for thorough mixing of ingredients in exact proportions.**—Agitation within the mixing chamber should be sufficient to secure a uniform mixture of the dry ingredients within an operating period of 5 minutes and to moisten every particle within another 5 minutes after the diluted poison is added. Chutes or hoppers of known capacity which can be loaded and emptied directly into the mixing chamber aid in securing the correct ratio of dry materials. Calibrated tanks or vats in which the proper amount of poison can be measured and diluted with the recommended quantity of water and from which exact quantities of the resulting solution can be discharged directly into the mixing chamber, are a great help in obtaining a uniform distribution of poison throughout the bait mixture.

(2) **Facilities for saving labor and speeding production.**—Careful planning of the mixing station as regards storage of supplies and

mixed bait and the location of mixing machinery is necessary to secure maximum efficiency. If a building is available where unloading of supplies and loading of mixed bait can be done on two different floors, much hand labor can be saved by storing supplies on the upper floor and allowing them to travel by gravity to measuring chambers directly above the mixing machinery on the floor below. If operations are limited to the ground floor, or if mixing is done outdoors, bait materials should be stored as close as possible to the mixing unit. Mechanical carriers are sometimes used to elevate dry ingredients into measuring chambers above the mixers, and drums of sodium arsenite are placed on elevated platforms from which the liquid poison flows by gravity into tanks near the mixing chamber.

FIGURE 18.—Mixing poisoned bait in a concrete mixer of the batch type. Note mechanical elevator for carrying measured quantities of millfeed and sawdust to the mixing chamber.

Water for diluting the poison can be piped directly to the tank in which the poison is diluted, and the resulting solution can be discharged by gravity directly into the mixing compartment.

Loading the measuring compartments above the mixer with all the materials needed for the following batch of bait, while the mixer is agitating one batch, materially increases the daily production. The mixing chamber should be constructed so that it can be emptied within a few seconds after agitation is completed. If mixed bait is emptied into a hopper leading into one or more bagging chutes it can be sacked with much less labor than when it is dumped on the floor and then shoveled into sacks.

(3) **Health and property safeguards.**—Mechanical devices which reduce the handling of poisons and mixed bait to a minimum, lower

the liability that mixing-station workers will be injured by too frequent contact with poisonous materials.

Possible theft of supplies, unauthorized loading of mixed bait, and access to dangerous materials by children and livestock should be guarded against by locking the building when the mixing plant is not operating. If the mixing plant is in the open, it should be tightly fenced and the gate to the enclosure locked when the plant is closed.

METHODS OF DISTRIBUTION

The prepared mash should be thinly and evenly scattered over infested fields at the rate of 10 to 15 pounds (wet basis) per acre. It is most commonly spread by hand (fig. 19). Every precaution should

FIGURE 19.—Spreading bait by hand for grasshopper control.

be taken to see that it falls apart into flakes. Casting it into the wind with a snap of the wrist helps to accomplish this. Several casts should be made with one handful of bait.

If large quantities of bait are to be distributed, scattering it from the rear end of a wagon or truck (fig. 20) permits two men to scatter it at one time as the vehicle is driven slowly over the field. One man scattering from a wagon can cover 10 acres per hour; two men in a truck can cover 20 acres. An end-gate seeder can be used, but it must be carefully watched and not allowed to clog because of too-rapid feeding.

Recently a number of inexpensive home-made or locally made bait-spreading machines have been developed with which from 30 to 40 acres can be covered in an hour. In one of the better types a circular sheet-iron disk 3 feet in diameter is mounted on an upright shaft so that the disk is 5 feet above the ground. The disk is fitted with radial blades about 2 inches high and is whirled rapidly by power from traction gears or a motor. Bait from a container mounted above is fed automatically upon the revolving disk and, when struck by the blades, is thrown with great force in a swath 30 to 40 feet wide, fall-

ing in evenly distributed flakes. Working plans and specifications for bait spreaders can be obtained from the Bureau of Entomology and Plant Quarantine and from some of the agricultural colleges in the infested area. Figure 21 shows a type of spreader that can be made by utilizing the rear end of an old automobile for both support and power, the original drive shaft serving to operate the larger pulley, which is belted to a small pulley under the disk.

The use of mechanical spreaders decreases the cost of spreading the bait and makes possible the treatment of large acreages during the comparatively short period of the day favorable to bait spreading.

FIGURE 20.—Scattering bait from the rear of a motortruck. (Photograph by courtesy of C. J. Drake, Iowa Agricultural Experiment Station.)

Where the terrain permits and where large, uniformly infested areas are to be treated, scattering by airplane is practical. Airplanes fitted with special equipment can cover 100 to 150 acres an hour. Their use in the United States has not been extensive because all available funds for grasshopper control are generally expended for materials, and the labor of spreading is usually provided by the landowners or tenants.

TIME OF DISTRIBUTING BAIT

The best time to put out poisoned bait is while the grasshoppers are on the ground, doing their first feeding of the day. This occurs as soon after sunrise as the air temperature reaches 70° to 80° F., usually between 6 and 10 a. m., but if it is cold or cloudy early in the morning it may take place later in the day. The bait should not be scattered when the temperature is below 70° or above 85° or if there is prospect of rain within a few hours. Cloudy and windy weather are also unfavorable for feeding. An easy way to determine whether conditions are right for bait spreading is to scatter a few handfuls of bait where grasshoppers are thick, and to observe them carefully for several minutes. If feeding on the bait begins at once, spreading should be continued. If grasshoppers refuse the bait, spreading should be delayed until more favorable conditions prevail. Spreading the bait when conditions are not right for feeding is the most common reason for poor kills and frequently results in wasting large quantities of bait.

Newly hatched grasshoppers usually remain for some time congregated on their hatching grounds. If possible, they should be poisoned while they are still confined to these places or before they have invaded crops. While bands of young grasshoppers are migrating, good kills can be obtained by spreading strips of bait across their line of march (fig. 22).

It is important to realize that the use of poisoned bait is far more effective when young grasshoppers are concentrated on headlands or in the margins of fields than after they have increased in size and are dispersed over an entire field. Baiting grasshoppers before they

FIGURE 21.—A mechanical bait spreader that utilizes the rear end of a discarded automobile to whirl the scattering device. (Photograph by Soil Conservation Service, U. S. Department of Agriculture.)

attack, or when they first invade crops, is one essential of a successful control campaign. Larger immature grasshoppers and adults are easily killed with bait after they have invaded crops, but much more bait and labor are required. One hundred and fifty pounds of wet bait spread over 10 acres may not kill as many large grasshoppers in crops as 15 pounds spread over 1 acre when they were small and densely massed at the field margins.

Grasshoppers do not die immediately after they have eaten the poisoned bait. The poison may require 36 hours or even longer to become fully effective. It makes them sick within a few hours, and they do little damage after having eaten a fatal dose. Sick grasshoppers seek shade and moisture and frequently die in great numbers under plants and clods or in cracks in the soil. Careful examination of such places should be made in judging results.

PRECAUTIONS NECESSARY IN HANDLING ARSENIC AND POISONED BAIT

Unless reasonable precautions are taken by persons engaged in mixing and scattering grasshopper bait, arsenical injury may result. Crude arsenic is a fine dust that readily rises and floats in the air, and when mixing is done indoors it frequently impregnates the clothing and comes in contact with the skin of workers engaged in mixing bait. Continued contact with arsenic may cause acute skin irritation. To prevent this, the following simple precautions are recommended: (1) A complete change of clothing and a bath after each day's work; (2) daily washing of garments worn while mixing bait; (3) wearing

FIGURE 22.—Young grasshoppers massed on a strip of poisoned bait spread across their line of march.

outer clothing that consists of firm-texture coveralls, heavy shoes (not oxfords), and gauntlet-type leather gloves, with soft cotton gloves inside. The coveralls should be fastened tightly around shoe tops and wrists and should have pockets sewed shut.

When liquid sodium arsenite is used there is less danger of skin irritation during the bait-mixing process, but continued contact with the moist bait may result in burns if workers are careless. For workers in mixing stations where liquid sodium arsenite is used the following precautions are recommended: (1) Grease the hands frequently with petrolatum, lanolin, or axle grease and work it under the fingernails; (2) wear heavy rubber or well-oiled leather gloves; (3) when lifting sacks of wet bait wear waterproof aprons; (4) if clothing becomes damp from contact with bait, remove the clothing and wash it thoroughly before wearing it again; (5) bathe the entire body thoroughly after each day's work.

Regardless of precautions, some workers are sure to be careless, and occasionally inflammation and burning of the skin occur. Slight irritation usually can be relieved by treatment with powdered zinc oxide, calamine lotion, or a saturated solution of sodium thiosulfate (photographer's hypo). Cuts and bruises are irritated by arsenic. They should be cleaned with sodium thiosulfate solution, followed by alcohol, and then covered with gauze bandages. Any cases which do not respond immediately to ordinary treatment should be referred to a physician.

In spreading bait, long-continued handling of the wet mash may result in irritation of the hands, particularly underneath the fingernails, and inflammation of the lower abdomen and legs may occur if clothing becomes dampened by contact with the sack or pail in which the bait is carried. Greasing the hands, working the grease beneath the fingernails, wearing a canvas or rubberized apron, and avoiding dampening of the clothing by contact with the bait will prevent such effects. After spreading is finished, the hands should be thoroughly washed with soap and water; if clothing has been wet by contact with the bait, the entire body should be bathed. Bait spreading is done every year by thousands of farmers, and to date no cases of serious injury have been reported.

Mixed-bait containers should be labeled "POISON" in large letters. The bait should never be left on wagons or trucks where horses or cattle can break open or lick the sacks containing it, and it should be stored in a building inaccessible to livestock and children.

Liquid that may seep from stored wet bait or washings from drums that have contained liquid sodium arsenite are a serious menace to human beings and livestock if allowed to stand in pools or to drain into wells. The best way to dispose of any poison liquid that may accumulate is to dip it up and empty it into the next batch of bait that is mixed. Ground that has been soaked with liquid poison should be plowed or turned with a spade after bait mixing for the year is completed.

Poisoned bait scattered in flakes is never picked up by livestock in sufficient quantities to cause poisoning. When bait is scattered at the recommended rate of 15 pounds of wet mash per acre, less than half a pound of arsenic (As_2O_3) is spread over 1 acre, and less than a quarter of a pound if liquid sodium arsenite is used. To obtain a fatal dose, a horse would have to eat every bit of bait on 575 square yards and a sheep all the bait on 145 square yards. Considering the difficulty that the animal would have in finding the small flakes of bran and sawdust and the fact that where properly scattered much of the bran is eaten immediately by grasshoppers, the possibility of livestock poisoning is exceedingly remote. If it is scattered in lumps and in larger quantities per acre than those recommended, animals may eat it with disastrous results. Farm animals have been killed by uncovering and eating left-over bait that had been buried months before in bulk in strawstacks and in the ground. Unused bait stored on the farm has sometimes been fed directly to livestock by careless farm laborers. Poisoned bait remaining after the baiting season is over should be stored in a county warehouse or scattered thinly over the ground in the same manner as when grasshoppers are present. The storing of unused bait on the farm during the winter months involves a hazard both to human beings and to animals. Sacks that

have contained the bait should be returned to the county mixing station or burned and the ashes buried in the ground. Drums that have contained sodium arsenite should not be used for hauling water for livestock.

GRASSHOPPER BAIT NOT DANGEROUS TO GAME BIRDS AND SONGBIRDS

Contrary to a widespread public impression, game birds and songbirds are not endangered by grasshopper-bait-spreading campaigns. In Iowa, employees of the State college, the Bureau of Biological Survey of the United States Department of Agriculture, and the State Conservation Commission, in cooperation with the American Wildlife Institute, kept a close check on 600 farms during the extensive poisoning campaign of 1936. Four hundred farms were moderately or heavily baited, but not a single game bird, songbird, rabbit, or other wild animal was observed to have died as a result of eating poisoned bran or poisoned grasshoppers. Instead, it was found that grasshoppers, where not controlled, destroyed the cover and winter food (weed seed, berries, etc.) of game birds, and the birds moved to other sections.

During the extensive grasshopper-baiting campaign in South Dakota in 1931 and 1932 there were numerous rumors of birds having been killed by grasshopper bait. The Bureau of Biological Survey placed a man in the State during the summer of 1932 to investigate such reports and to check baited farms for sick or dead birds, but he was unable to find an authentic case of poisoning.

F. E. Whitehead, of the Oklahoma Agricultural Experiment Station has made extensive experiments in feeding poultry, quail, and songbirds both grasshopper bait and poisoned grasshoppers. He found that it required a surprisingly large quantity of arsenic to kill such birds, and that even when they fed to capacity on bait or poisoned grasshoppers they did not obtain a toxic dose. Even when domestic poultry were confined in pens where bait was scattered at the rate of 100 pounds to the acre, or 10 times the amount used in grasshopper control, and were given no other food, none died.

During the extensive grasshopper campaigns conducted from 1934 to 1937, county agents in every county where poisoned bait was used were requested to watch for and investigate any reported cases of killing of game birds or songbirds. Not a single proved case was reported.

TILLAGE AND SEEDING METHODS

It is realized that in many localities, owing to soil and weather conditions and the species of grasshoppers present, some of the cultural methods suggested below may not be applicable. This may be particularly true in areas where soil blowing is a problem. In such cases county agricultural agents and State college agronomists and entomologists should be consulted in developing a tillage and seeding program that will provide as much grasshopper control as is consistent with approved local farming methods. Where the grasshopper infestation is severe enough to threaten the loss of an entire crop, it may be advisable to modify the usually approved cultural program so as to take advantage of all available measures for the control of grasshoppers.

Several common tillage methods can be used to great advantage before and after the grasshoppers hatch. Eggs can be destroyed or

buried so deeply that the newly hatched grasshoppers cannot reach the surface. Migrations of young grasshoppers can be restricted by plowing or harrowing. Correct timing and methods of seeding lessen the likelihood of crop injury. Such practices may not eliminate the necessity for using bait, but they reduce the quantity required and the labor needed in spreading it.

PLOWING

Good plowing with a moldboard plow to a depth of at least 5 inches is the best known method of preventing the emergence of young grasshoppers from the ground (fig. 23). In average soil and with fair moisture conditions insignificant numbers escape, even though the soil contains great numbers of eggs. Plowing with a disk or one-way plow is usually only half as effective because the furrow slice is only partly turned over. Disk plows fitted with an attachment for turning the furrow slice more completely are satisfactory provided the upper 2 inches of soil which contains the eggs can be turned under to a depth of 5 inches.

Fall plowing, when moisture conditions are favorable, is slightly more effective than spring plowing because rain and melting snow seal and harden the upper layer of soil and make it more difficult for the young grasshoppers to escape. Spring plowing, combined with packing, is as effective as fall plowing and in many districts is a much more desirable practice from the standpoint of crop yields and prevention of soil blowing. If spring plowing is followed immediately by seeding with a press drill no other packing is necessary. If a press drill is not used or if seeding is delayed, packing is needed to close cracks and firm the surface layer. The cultipacker or the spike-tooth harrow is the best implement to use, from the standpoint of firming the soil and leaving the eggs deeply buried. Light, sandy soil or heavy soil that is extremely dry cannot be packed firmly enough to hold the young grasshoppers in the ground, and under such conditions plowing is not recommended.

Grasshopper-infested stubble land which is to be summer-fallowed should be plowed before the eggs hatch, but if plowing is delayed until after the young grasshoppers have appeared it can still be used as a means of preventing their moving to nearby crops. In this case a barrier strip 4 rods wide should be plowed around the entire field. If this strip is kept cleanly fallowed the young grasshoppers can be held in the field for several weeks, and there may be time to complete the plowing before they leave. If the infested field is large, it should be divided into strips and each strip then worked by plowing around the outside until only a narrow unplowed area in each remains. If plowing is done during cool weather or at night while the grasshoppers are sluggish many will be turned under and killed. Those that escape are forced to the unplowed strips, where they can be poisoned with small quantities of bait.

The time during which young grasshoppers will remain in fields without traveling across plowed guard strips depends on the food supply and weather conditions. Where green food is scarce, the weather warm, and large numbers of grasshoppers are present, early migrations may be expected. Unplowed fields, even though protected by guard strips, should be carefully watched, and if bands of young

FIGURE 23.—*A*, A field containing wheat stubble heavily infested with grasshopper eggs. It was plowed to a depth of 5 inches and seeded on April 20. *B*, the same field 6 weeks later. The eggs were buried so deeply that few grasshoppers emerged, and the new crop shows no damage.

hoppers start to move out they should be baited immediately. Every effort should be made either to complete plowing or to kill the young grasshoppers by baiting before they develop wings and fly to crops.

SHALLOW TILLAGE

Shallow cultivation has long been recommended for the destruction of grasshopper eggs, but it has seldom given dependable control. To kill grasshopper eggs by such means, the eggs must be brought to the soil surface where they are exposed to the drying effects of weather. Under certain conditions eggs exposed in this way may be rendered unhatchable within a few hours, but under other conditions they may remain exposed for days or even weeks without harm and eventually become again covered by drifting soil or subsequent cultivation. Furthermore, no implement has yet been devised that will bring all the eggs to the surface and leave them there. A fairly high percentage are always left with enough covering to protect them until they hatch, and, if the original infestation was severe, grasshoppers may afterward emerge in dangerous numbers. Where shallow tillage fits into recommended farm practices, it should be used as a means of reducing the number of live grasshopper eggs, but it cannot be depended upon so to protect crops that subsequent baiting will not be necessary. Cultivation is most effective in killing grasshopper eggs during dry weather when the shriveling effects of wind and sunshine are greatest. To obtain maximum killing effects several workings should be given.

The duckfoot cultivator is the best shallow-tillage implement for destroying grasshopper eggs in grain stubble. It has broad V-shaped blades which cut or pull loose the roots of weeds and grain stubble and push the crowns to the surface. The upper crust of soil is also broken and left in clods. Egg pods attached to the crowns and roots of plants or embedded in clods are brought to the surface and left exposed to the weather. Grasshopper eggs are laid in the upper 2 inches of soil, and cultivation is most effective when the duckfoot blades are adjusted to cut just beneath the egg-containing layer.

The use of disk and tooth harrows brings many eggs to the surface, but these implements are not so effective as the duckfoot cultivator in working grain stubble for this purpose. The spring-tooth harrow is useful in cutting down grasshopper populations in alfalfa fields which, when left undisturbed, frequently become grasshopper-breeding grounds. Shallow cultivation with the spring-tooth harrow, late in the fall or early in the spring, destroys some eggs and leaves the field in a condition less attractive for egg laying.

SEEDING METHODS

Seeding only on fall- or spring-plowed land, or on clean summer-fallowed ground is of vital importance in protecting small grain crops during grasshopper outbreaks. Few grasshoppers will hatch within fields that have been thus treated, and efforts can therefore be concentrated on baiting those hoppers originating outside and attacking the margins of the crops. By this method the quantity of bait needed and the labor of spreading are reduced far below the requirements for baiting the entire field, and the crop will have time to reach a stage that is more resistant to grasshopper attacks.

Seeding on ground handled in any other way may result in grasshoppers hatching throughout the entire field while the crop is only a

few inches high. When this occurs prompt baiting of the whole field is the only way to prevent serious injury. When an entire field of several hundred acres is suddenly attacked by grasshoppers that have hatched within it, serious damage may take place before bait can be obtained and applied. If the fields are invaded from without, progress of the hoppers into the crop usually is slow and by prompt application of poisoned bait can ordinarily be halted with only slight injury at the point of attack.

Where seeding is done on land that has not been plowed or summer-fallowed, the ground should be given at least shallow cultivation with a duckfoot cultivator or disk harrow, preferably in the fall and again

FIGURE 24.—Seeding grain in worked stubble. This is poor farming and is particularly dangerous during grasshopper outbreaks. Grasshopper eggs are not injured by the seeding process and may hatch throughout the field and destroy the crop before bait can be obtained.

during dry weather in the spring. This destroys some of the eggs and gives the farm operator a better chance to save the crop by baiting.

Stubbling in (fig. 24), or seeding grain directly into fresh grain stubble without preliminary tillage of any kind, is a common practice. It is condemned by agronomists because of reduced yields, and is the worst possible practice from the standpoint of grasshopper control. The seeding process destroys few, if any, of the eggs, and if the field is heavily infested it will be swarming with young hoppers immediately after the hatching period. Baiting the entire field within a few days after the hatching is the only method that may save the crop under such conditions.

Early seeding is frequently an important factor in reducing grasshopper damage. Crops that have made considerable growth before grasshoppers have hatched can withstand a longer period of feeding, which in turn affords a longer period during which baiting can be done. Even though a grower may prevent grasshoppers from maturing on his own farm, adults subsequently may fly in and attack his crops.

Late-seeded crops that are green and succulent at such times are particularly attractive to adult grasshoppers and often are severly injured before bait can be applied. Well-advanced crops usually fare much better, and such crops as wheat and barley can withstand considerable leaf destruction after the heads have formed without serious reduction in yield of grain.

In a locality for which a severe grasshopper outbreak is predicted, growers should carefully consider the acreage to be planted and the method of seeding to be adopted. It is better economy to restrict seeding to fewer acres and to ground from which few grasshoppers are expected to emerge than to seed a large acreage in which enormous numbers of grasshoppers are sure to develop. The first method reduces the investment at stake and greatly increases the chance for a margin of profit. The second requires a greater initial outlay and creates the hazard of total loss of a farmer's own crop and perhaps that of his neighbor.

CHOICE OF TILLAGE AND SEEDING METHODS GOVERNED BY LOCAL CONDITIONS

Several ways of reducing grasshopper injury by tillage and seeding practices have been described. Use of these is of greatest importance in the Great Plains region, where the migratory grasshopper is the most destructive species. This grasshopper's habit of laying its eggs throughout the current year's grain crop makes it particularly susceptible to control by plowing. In any control program in sections where it is the dominant grasshopper the practices of seeding only on clean summer-fallowed or newly plowed ground and of plowing stubble before the grasshoppers have hatched are highly desirable, from the standpoint both of crop protection and reduction in the quantity of bait needed ultimately for control.

The two-striped grasshopper and the differential grasshopper lay most of their eggs around the edges of fields that are in crops and along ditchbanks, fence rows, and roadsides. Hence plowing in connection with the preparation of land for seeding does not destroy a large portion of their eggs, but much good can be done by plowing headlands and fence rows, where feasible, after egg laying has been completed.

Plowing or shallow tillage of larger tracts of sod or idle land to control any kind of grasshoppers is not recommended unless the land is to be seeded or summer-fallowed immediately. Cultivation ruins such land for pasture and makes it subject to soil blowing, and the operation is more expensive than letting the grasshoppers hatch and then killing them with poisoned bait.

ADDITIONAL SUGGESTIONS FOR CONTROL

BARRIER STRIPS

When young grasshoppers are hatching in sod land adjacent to a crop likely to be attacked, their advance into the crop can be retarded by plowing a strip between the field and the sod land. If several deep furrows with sharp sides are plowed, the young hoppers will gather in them and can be killed there by daily applications of poisoned bait.

TRAP STRIPS

Grasshoppers frequently are very abundant in alfalfa and other hay crops at the time of the first cutting. If narrow strips of such crops around the edges or in the middle of the field and along irrigation

ditches are left uncut, grasshoppers from all over the field will gather in them and can be easily poisoned there.

BURNING

At night, and even in the daytime during cool weather, grasshoppers seek protection. At such times great numbers of them can often be killed by scattering straw or weeds where they are congregated late in the afternoon and burning it at night after they have crawled into it and become sluggish.

POULTRY

Flocks of turkeys or chickens eat great numbers of grasshoppers and can sometimes be used to advantage in small local outbreaks.

CATCHING MACHINES

Various kinds of grasshopper-catching machines (fig. 25) have been largely used in the past, but they are no longer recommended unless

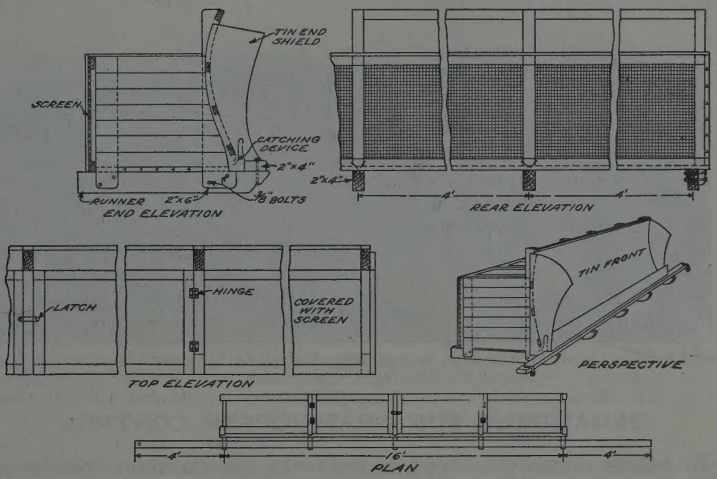

FIGURE 25.—Where it is desired to catch grasshoppers for poultry food, the grasshopper catcher is useful. It may be constructed according to the specifications shown in this illustration.

it is desired to save the grasshoppers for poultry food or fish bait. The poisoned bait is far more effective and is cheaper.

IMMUNE CROPS

Some of the sorghums, such as sorgo and kafir (fig. 26), after reaching a height of 8 to 10 inches are practically immune to grasshopper attacks. They can be planted rather late in the season and provide valuable feed for livestock in areas where control measures have not been applied in time to save other forage crops.

CASTOR-BEANS NO PROTECTION AGAINST GRASSHOPPERS

The erroneous idea has been rather widely held that grasshoppers may be poisoned by planting castor-beans around and through the crop to be protected. Experiments conducted by this Bureau and

several State experiment stations indicate that this practice has no value. When given no other food than castor-bean foliage, grasshoppers will eat sparingly of it and will die in about the same time as when given no food. When they are given a choice, other plants are preferred. Young grasshoppers have been reared to the winged stage in cages containing growing castor-bean and oat plants. They thrived on the oats, refused to more than nibble on the castor-beans, and grew to maturity in spite of being confined with plants that were supposed to kill them.

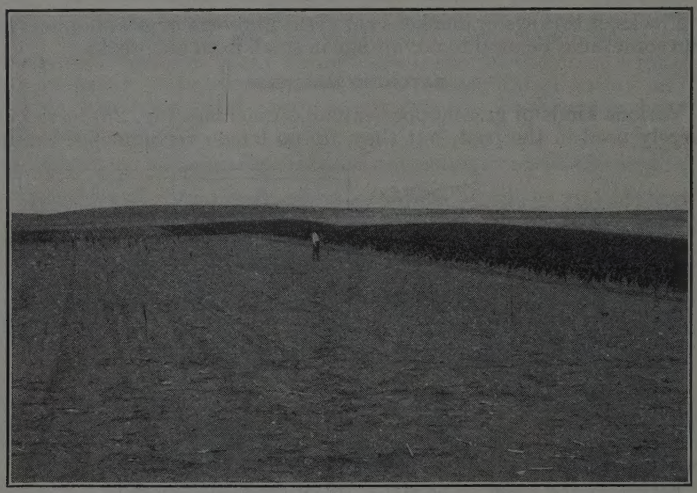

FIGURE 26.—Corn, on the left, completely destroyed by grasshoppers; sorghum, on the right, uninjured.

ORGANIZING FOR GRASSHOPPER CONTROL

In States where grasshopper outbreaks are common, yearly surveys are conducted to determine where control measures may be needed the following year. Farmers are urged to assist in these surveys by reporting the presence of unusual numbers of grasshoppers or grasshopper eggs to their county agricultural agent or State entomologist. Information on the distribution and abundance of grasshoppers within the county can be obtained from the county agricultural agent after the annual surveys are completed.

Where grasshoppers originate on a particular farm and menace only the crops on that farm, individual action is sufficient. If, however, they are present in such numbers that they are likely to move from one farm to another, community and often county-wide action becomes necessary. This can be secured only through proper organization, education, effective leadership, and adequate financial backing (fig. 27). Lacking any one of these essentials, a large-scale grasshopper campaign cannot be successful. Unless a suitable organization already exists, one should be started. It may well be a farm bureau, farmers' union, community club, or other farmers' organiza-

tion, headed by an active, efficient chairman. The following type of county organization is suggested:

(1) One executive—the county agricultural agent, if there is one—should be in charge of the campaign for the county. He should be responsible for funds expended, purchase and apportion supplies, instruct community leaders in the methods to be employed, and make contact with State entomological leaders so as to obtain the latest information on grasshopper control.

(2) There should be community or township chairmen to act as local supervisors under the direction of the county leader.

(3) Under these community chairmen there should be foremen of mixing and distributing centers to receive materials, to oversee mixing

FIGURE 27.—Cooperative community action in bait spreading. Businessmen from town with mechanical bait spreaders attached to their automobiles are assisting farmers and ranchers in a successful grasshopper-control campaign in which volunteer crews are baiting all infested land regardless of ownership.

of materials, and to check out mixed materials to individual farmers and scattering crews.

(4) Finally, captains of scattering crews, men well acquainted with grasshopper conditions and familiar with the correct method of scattering poisoned bait, should supervise the crews of men who scatter the bait in the field.

Farmers should cooperate and poison all grasshoppers regardless of where they are found. Cleaning up an entire community or township will not only save current crops but will eliminate the necessity for or greatly reduce the scope of control measures needed the following year. It should be emphasized that this is not a mere visionary ideal that can never be reached but an objective that has frequently been attained. A well-planned campaign, started early and pushed to completion before the grasshoppers become winged, will in most cases prevent serious crop losses. But if action is delayed to see what is going to happen or until the grasshoppers are doing serious damage and flying from one field to another, complete success cannot be expected.

ORGANIZATION OF THE UNITED STATES DEPARTMENT OF AGRICULTURE WHEN THIS PUBLICATION WAS LAST PRINTED

Secretary of Agriculture	HENRY A. WALLACE.
Under Secretary	M. L. WILSON.
Assistant Secretary	HARRY L. BROWN.
Coordinator of Land Use Planning and Director of Information.	M. S. EISENHOWER.
Director of Extension Work	C. W. WARBURTON.
Director of Finance	W. A. JUMP.
Director of Personnel	Roy F. HENDRICKSON.
Director of Research	JAMES T. JARDINE.
Solicitor	MASTIN G. WHITE.
Agricultural Adjustment Administration	H. R. TOLLEY, *Administrator.*
Bureau of Agricultural Economics	A. G. BLACK, *Chief.*
Bureau of Agricultural Engineering	S. H. MCCRORY, *Chief.*
Bureau of Animal Industry	JOHN R. MOHLER, *Chief.*
Bureau of Biological Survey	IRA N. GABRIELSON, *Chief.*
Bureau of Chemistry and Soils	HENRY G. KNIGHT, *Chief.*
Commodity Exchange Administration	J. W. T. DUVEL, *Chief.*
Bureau of Dairy Industry	O. E. REED, *Chief.*
Bureau of Entomology and Plant Quarantine	LEE A. STRONG, *Chief.*
Office of Experiment Stations	JAMES T. JARDINE, *Chief.*
Farm Security Administration	W. W. ALEXANDER, *Administrator.*
Food and Drug Administration	WALTER G. CAMPBELL, *Chief.*
Forest Service	FERDINAND A. SILCOX, *Chief.*
Bureau of Home Economics	LOUISE STANLEY, *Chief.*
Library	CLARIBEL R. BARNETT, *Librarian.*
Bureau of Plant Industry	E. C. AUCHTER, *Chief.*
Bureau of Public Roads	THOMAS H. MACDONALD, *Chief.*
Soil Conservation Service	H. H. BENNETT, *Chief.*
Weather Bureau	F. W. REICHELDERFER, *Chief.*

U. S. GOVERNMENT PRINTING OFFICE: 1939

For sale by the Superintendent of Documents, Washington, D. C. - - - - Price 10 cents